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AN OPEN-OCEAN V/STOL SEAPLANE FOR THE ASW MISSION
(Title Unclassified)

by

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Foreword

This paper was initially presented at the AIAA/USN Marine Systems and ASW Conference in San Diego, California, March 10, 1965. The results presented were derived from an independent in-house exploration of the potential of a V/STOL vehicle. Publication of the results does not imply endorsement by any organization other than the Aerodynamics Laboratory itself. The authors gratefully acknowledge the assistance of the following individuals for their contributions in the maintenance of a realistic approach to operational aspects: CAPT C. W. Griffing, ONR; Mr. F. W. S. Locke, Jr., CDR R. K. Geiger, Mr. R. L. Parris, Mr. K. E. Dentel, and LCDR P. L. Dudley, Jr., BuWeps.

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SYMBOLS

b	wing span in feet
$\bar{c}$	lifting-surface mean aerodynamic chord (M.A.C.)
L	lift in pounds
D	drag in pounds
V	velocity in feet per second
V_k	velocity in knots
P	power in pound-feet per second
W	vehicle weight in pounds
S_m	reference momentum area in square feet $\left(\frac{\pi b^2}{4}\right)$
d	propeller diameter in feet
n	rotational speed in revolutions per second
c_ℓ	propeller airfoil section lift coefficient
$\frac{LV}{P}$	equivalent lift-drag ratio
$\frac{P}{W\sqrt{\frac{W}{\rho S_m}}}$	power parameter
$\frac{V}{\sqrt{\frac{W}{\rho S_m}}}$	speed parameter
M	vehicle Mach number
M_T	propeller tip helical Mach number
β	propeller reference blade angle
ρ	atmospheric air density in slugs per cubic foot
η	propulsive efficiency
η_i	propulsive efficiency at subcritical tip Mach numbers, incompressible
$\frac{\eta_{max}}{\eta_i}$	maximum propulsive efficiency ratio, compressible-to-incompressible

Normal Rated	maximum continuous engine power setting
Mil	military engine power setting
TO	take-off engine power setting
TP-SS	engine, turboprop, single shaft
TP-DS	engine, turboprop, double shaft
RTP-SS	engine, regenerative turboprop, single shaft
RTP-DS	engine, regenerative turboprop, double shaft
APU	auxiliary power unit
Rest	condition of waterborne ASW tactical surveillance

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SUMMARY

A V/STOL Open-Ocean Seaplane with good payload/range capability and high seaworthiness characteristics has been investigated for specific ASW missions. The results from a simulation program of the contact maintenance mission on the IBM 7090 computer, using the predicted performance of the seaplane design and the projected capability of the Air Transportable Sound Surveillance System (ATSSS), indicate a good potential for the seaplane in passively tracking of on-station nuclear submarines. The application of the seaplane to other ASW missions (contact investigation and the temporary barrier) is also considered. The special configuration limitations and performance considerations involved in the preliminary design of the 93,000-pound V/STOL seaplane are outlined.

INTRODUCTION

The Aerodynamics Laboratory of the David Taylor Model Basin has been involved in the research and development of Vertical and Short Take-Off and Landing (V/STOL) Aircraft for the past fifteen years. However, only in the last two years has a concentrated effort been devoted to conceptual design. This two-year period started with a review of the information available from earlier test and development programs in the V/STOL field.

Figure 1 is the result of a performance estimate for several concepts, including a modern tilt-wing transport. It is a plot of the equivalent lift/drag ratio versus a nondimensional speed parameter, essentially a power-required concept. Notice that the early V/STOL concepts produced maximum lift/drag ratios of less than 4. It must be remembered that these were, essentially, test-bed vehicles, and were not designed for optimum cruising performance. However, compared with the helicopter, these vehicles were less efficient cruise machines; and, since this type of vehicle is always a less efficient device in hovering flight, they represented no specific advantage, except for speed. Also, the speed capabilities which many of them possessed could not be utilized in a military environment because the payload vanished in the fuel requirement. Only the tilt-wing transport showed any promise of being an efficient vehicle (Reference 1).

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DESIGN CONSIDERATIONS

From these available data, the Aerodynamics Laboratory staff set up certain study criteria. They were: that the payload/range characteristics of any designed vehicle are paramount, that the design must be an evolutionary development of standard aircraft design practice, and that an equivalent lift/drag ratio of less than 10 would automatically disqualify a primarily load-carrying vehicle. The transition characteristics were to be subordinated, although not neglected, in favor of increasing the cruise potential. The initial considerations for design concepts and mission formats led to severe limitations on configuration. The aircraft in question could not be made clean enough, aerodynamically, to give a fair evaluation of the efficiency potential of future V/STOL concepts. The outgrowth of this dilemma was a diversion of attention to an Open-Ocean Seaplane, where configuration limitations were minimal.

The primary design consideration was the selection of the propulsion group. Figure 2 is the classical power-loading/disc-loading curve for hovering flight (Reference 2). In the low disc-loading area at the left of the curve, representing the region of helicopters, successful operation over water has been performed. The jet-surface loadings associated with jet-lift systems, shown at the right of the curve, are expected to be too high for a vehicle to exhibit satisfactory handling qualities in a marine environment. Although it has not been satisfactorily evaluated to date, it is assumed that an allowable disc loading of 50 pounds per square foot is compatible with water surface operations. The problems identified with operation in a marine environment need further clarification; and full-scale testing is probably necessary to establish a definite disc-loading boundary. The selection of 50 pounds per square foot indicates the desirability of a free-propeller configuration. With this hover disc loading, a 90,000- to 100,000-pound vehicle could be supported by six 20-foot-diameter propellers.

VEHICLE CONFIGURATION

The resulting vehicle configuration (Figure 3) is a six-engine canard seaplane with a fully developed hull to accommodate the STOL flight requirement. The aircraft is about the size of a P3-A (ORION).

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The canard arrangement gives a location for the six engines within reasonable structural considerations and offers the advantage of longitudinal trim control in hover and transition without the use of a tail rotor. The vertical and short take-off lifting capabilities of the aircraft are considered to be 93,000 and 115,000 pounds, respectively. The "no fuel" operational weight should be about 81,000 pounds. Figure 4 presents the major dimensions of the seaplane in a two-view drawing, and Table 1 summarizes additional configuration specifications.

PREDICTED PERFORMANCE

Figure 5 shows the predicted performance of the DTMB seaplane in comparison with the early vehicles. It is noted that the predicted equivalent lift/drag ratio is in excess of 10, the initial limit for acceptability. The value used for propulsive efficiency was 0.80 in the generation of the seaplane curve. These data can be viewed in a modified form, the nondimensional power versus speed parameter, as shown in Figure 6. Looking at the data in this manner leads to the often-stated argument that the cruise power requirements for VTOL aircraft are about one-third of the installed power. This observation immediately suggests that with a six-engine vehicle, cruise might be effected with two engines at high power, four engines at medium power, or six engines at low power. An investigation of the propulsive efficiencies and fuel consumptions of various engine combinations is required to establish the most efficient operation. Maintaining a high performance level is dependent upon maintaining high propulsive efficiency for all flight requirements. Very clean aircraft with inefficient propulsive systems will show up poorly when compared with well-matched powerplant/airframe combinations.

PROPULSION CONSIDERATIONS

The curves of Figure 7 indicate how the maximum propulsive efficiency is degraded as the tip Mach number of the propeller is increased beyond 0.9 (Reference 3). These curves do not take into account the most recent technology in contemporary propeller design which may include using variable geometry to achieve high static thrust with minimum compromise of cruise efficiency. Excluding the merits of the yet unproved variable-geometry propellers, the curves do indicate that in the design of a free-propeller

VTOL vehicle (where static conditions dictate the selection of propeller diameter and power train gearing), seemingly well-matched propellers may not retain a high propulsive efficiency when operating at an altitude cruise condition. If the tip speeds are not maintained near a maximum permissible level in the hover condition, where the demands on the propulsion system are the greatest, there will necessarily be a weight penalty in the entire propulsive group. Assuming that this requirement exists for the particular design under consideration, one should look at the resulting tip speeds under cruising flight conditions. The propeller helical tip Mach number for the forward flight condition is given by:

$$M_T = M\sqrt{\left(\frac{\pi n d}{V}\right)^2 + 1}$$

At the cruising altitudes and speeds considered for most ASW mission profiles, the aircraft cruise Mach number would be between 0.4 and 0.5. To avoid the compressible flow losses associated with operating a conventional propeller above a tip Mach number of 0.9, one or more of the variables appearing in the expression must be decreased. With a given flight speed and altitude, and the propeller diameter fixed, only engine rotational speed (n) can be diminished. Old piston engines provided this reduction in rpm for the cruise power settings; however, simple turbo machinery, running at nearly constant rpm for any power setting, does not. The conclusion may be drawn that efficient VTOL aircraft may require more complex engines.

Figure 8 shows the characteristic propeller shaft speed reduction of four turboprop engines as a function of percent normal-rated power. The single-shaft turboprop (TP-SS) engine shows no speed reduction with a decrease in power. The double-shaft turboprop, or free-turbine (TP-DS) engine, shows almost 20 percent rotational speed reduction at 40 percent power; and the single-shaft regenerative (RTP-SS) engine shows a similar speed reduction at 35 percent normal rated power (see References 4 through 6). The curve also shows an RTP-DS engine with approximately 30 percent reduction in turbine speed at low power. Such an engine would be a free turbine with a regenerative cycle. This engine is suggested as the type which may be necessary to optimize performance over the large span of flight requirements for VTOL aircraft, including vertical take-off and high-speed cruise.

In addition to considering turbine speed, which changes air horsepower output through the propeller efficiency, it is necessary to consider the specific fuel consumption (sfc) at desirable power settings. The desirable effect of reducing turbine speed at low power will be lost if the engine sfc is high. For example, turbine speed characteristics of the free turbine (TP-DS) shown are nearly satisfactory with the engine operating near 40 percent power. However, the sfc at this power setting is approximately 30 percent higher than the sfc at full power. At approximately the same low percent power, the sfc of the regenerative turbine (RTP-SS) is significantly lower than that at full power (approximately 10 percent). With all stages of the single-shaft regenerative engine interconnected, this engine does not offer the ultimate in turbine output speed characteristics. The engine suggested as desirable for free-propeller VTOL aircraft would essentially incorporate the best features of the free turbine (speed relaxation) and the regenerative cycle (low sfc at low power). This is probably a complex engine with variable geometry in both ends of the gas cycle.

If the cruise speeds for the aircraft require the maximum reduction in engine rotational speed to maintain high propulsive efficiencies, then one should consider that engine power in cruise may be reduced to as low as 35 percent of normal rated power. The turbine characteristics would then indicate that under most conditions this six-engine aircraft should be cruised with all engines running at the lowest power setting. Some consideration may be given to four-engine operation, but it is believed that speeds for two-engine operation in the efficient cruise range would be too low for the projected requirements of this aircraft.

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Many VTOL design concepts have not given serious consideration to propulsive efficiency in cruise. Looking at this problem for each individual design makes many of them unacceptable.

Performance predictions for this vehicle have been made using the engine specifications of a single-shaft, regenerative turboprop engine (Reference 6). The regenerative turboprop is considered to be a reasonable state-of-the-art engine development, although no engines of this type are presently in service.

PERFORMANCE TRADEOFFS

When attention is directed toward a specific aircraft speed, it is necessary to select the operating point on the power/speed curve or equivalent lift/drag curve. If payload/range characteristics are of primary importance, cruise must be at the maximum equivalent L/D. Cruising at $(L/D)_{max}$ is possible for all aircraft, but it often requires flying at higher altitudes or lower speeds than are desirable. Flying at $(L/D)_{max}$ is not considered for the seaplane. Recommendations issued by Air Programs, Naval Application Group of the Office of Naval Research indicate that a cruise speed of the order of 300 knots, or greater, is desirable for most ASW missions (Reference 7). To approach a speed of 300 knots within altitude limits, it is necessary to fly the seaplane "off" $(L/D)_{max}$; that is, off its most efficient cruise point. A performance analysis has been completed to weigh the tradeoffs in payload/range against an increase in speed. A slight reduction in aerodynamic efficiency results in a proportional increase in the fuel requirement. This vehicle should be capable of accepting the penalty of flying "off design" to achieve acceptable cruise speeds. The additional fuel load required will not make the vehicle overweight if the initial take-off is assumed to be in the short take-off mode. It is the vertical take-off or vertical landing weight that represents the limiting weight of the aircraft. It will be necessary to fuel the aircraft with a specific mission in mind so that transit fuel burn-off will allow arrival in the tactical area at design VTOL weight.

Figure 9 shows the aircraft's performance at various weights for an equivalent lift/drag ratio of 10.35. The two curves which define the

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performance of the airplane, within propeller-tip Mach-number limits of 0.9, are the predicted performance of a regenerative turboprop (RTP-SS) and the hypothetical VTOL engine (RTP-DS). With the regenerative turboprop, speeds from 260 to 290 knots are attainable at altitudes from 21,000 to 16,000 feet. At these speeds, the specific range of the aircraft, in miles per pound of fuel, is almost constant at 0.095. The hypothetical engine allows a significant improvement in aircraft efficiency, but only by operating at very high altitudes (above 25,000 feet). These altitudes are not considered consistent with mission requirements. Furthermore, the hypothetical engine installation does not produce a significant increase in the seaplane cruise speed.

WIND-TUNNEL TESTS

Wind-tunnel tests have been conducted in the 8- by 10-foot subsonic facilities at the Aerodynamics Laboratory, Taylor Model Basin to determine the handling qualities, transition stability and control, and flight performance of the V/STOL seaplane. Figure 10 shows the unpowered version of the model in its cruise configuration. Figure 11 shows the powered model in the hover mode. These tests involve tilting the wings to establish the trim conditions throughout the transition phase of flight.

Results of the tunnel tests to date indicate that the configuration, as shown, demonstrates slight static longitudinal instability in cruise. The drag measurements, when compared with finite wing theory, substantiate the prediction that the downwash from the canard destroyed the elliptic lift distribution on the main wing. Results of the wind-tunnel tests for the seaplane cruise performance are reported in Reference 6, and a report of transition characteristics is in preparation.

It is predicted that a modification in the aircraft geometry can result in a substantial resolution of these problems. A small investigation for the optimization of high-aspect-ratio canard configuration geometry is planned.

AIRCRAFT SYSTEMS

In discussion with personnel in the ASW Office of the Bureau of Naval Weapons, the suggestion was made that consideration be given to the Air

Transportable Sound Surveillance System (ATSSS) buoy concept, the active-passive unit now under development (Reference 9). This system would provide the aircraft with multi-sensor deployment; it would prevent data degradation from towing effects; and it should give unbroken target contact during aircraft manuevers. The ATSSS buoy is shown in Figure 12. While the ATSSS concept considers both active and passive operation, it was further suggested that if the system were to be used only passively for target tracking, a buoy designed for purely passive operation might have only half the weight of the ATSSS system (about 1,500 pounds), a three-fold increase in battery life could be expected (permitting nearly 24 hours of operation), and the bearing accuracy might be improved in the passive mode to $\pm 3^{\circ}$. The cyclic operation would be approximately the same as the initial ATSSS concept--15 minutes to lower the array and 30 minutes to raise it. It is assumed that the size would remain the same as that of the original buoy concept. It is further considered that a modified A-New Data Handling System would be incorporated in the airplane. The system modifications would delete items not required to perform the mission selected. Other systems considered for the aircraft are: a limited Jezebel capability, 180°-scan radar, low-light-level TV, and automatic ECM.

An artist's conception of the seaplane in a functional layout is presented in Figure 13. The seaplane is shown sitting on inflatable vertical floats. The tactical layout is considered to be a Mod-2 A-New system. Volume requirements for specified equipment have been considered, using standard aircraft rack sizes. Minimum personnel requirements would include: a three-man flight crew, a five-man tactical crew, and a buoy handler. The inset, Figure 13, shows the stowage location for four buoys: two aft of the main wing and two in a trough under the floor of the data compartment. These buoys will be ejected and retrieved through a buoy shoot aft of the main support float. A large portion of buoy handling would have to be done with automated power equipment because of their weight and size. Proposals are in existence whereby buoy deployment and retrieval should be operationally feasible.

ASW MISSIONS

The seaplane has been considered for three ASW missions: contact maintenance (tracking), contact investigation, and the temporary barrier. It is not implied specifically that the seaplane cannot perform such missions as convoy and task-force screening, amphibious area screening, and open-ocean search. It is, however, believed that these missions can be more economically performed by other vehicle systems.

CONTACT MAINTENANCE

The principal mission for the seaplane is considered to be that of maintaining contact with enemy nuclear submarines for extended time periods. It is further considered that continuous tracking would be in a passive mode of operation without the submarine being aware of the aircraft's presence. Contact maintenance presupposes target localization by some other means. Target localization by some other means signifies that contact maintenance is essentially the take-over of a tracking command. Figure 14 shows the sequence of events to complete a mission command change. Considering the case of a target 1,000 miles from the base harbor, transit and buoy deployment--from cold start to rest--can be effected in 4 hours and 18 minutes. Near the end of the cruise-out leg of transit, the tactical coordinator (TACCO) would initiate an interrogation of the computer on board the vehicle holding the target. This interrogation would be done via automatic radio data link, where the memory in the tactical computer is read into the memory of the arriving aircraft. When the interrogation is completed, a data presentation is available in both vehicles. Hence, a determination of the most effective buoy deployment can be made by the arriving TACCO. This degree of coordination allows the arriving aircraft to transition and effectively deploy three of its four buoys in the 4 hours and 18 minutes.

The basic tracking or contact maintenance mission is shown in Figure 15. It is believed that this coverage represents a satisfactory level of passive localization, if attack is not imminent. The aircraft is sitting at position 1, with buoy 1 on board. Buoys 2, 3, and 4 are deployed. The circles around each buoy represent the acoustical range (24 kiloyards) for 40 percent detection probability against a 5-knot submarine. Notice that buoy 2 is rapidly becoming useless to the tactical situation, since its detection probability is down to 20 percent. These percentages, functions of buoy detection range and submarine speed, form the basis for an assessment of the tactical situation in a mathematical analysis.

The detection probabilities are used as a set of limits for establishing seaplane maneuvering requirements; i.e., the percentage associated with any one buoy must be at least 20, the percentages for any two buoys must total 50, and the percentages for all three buoys must total 120. These specific limits, together with other "fix" quality criteria determine that the buoy deployment shown in Figure 15 is satisfactory and the seaplane should remain at rest.

In an actual passive tracking situation, signal strength in a given sea environment is a function of submarine speed and the signal is attenuated as a function of range. These acoustical energy phenomena will influence the quantity and quality of data available from any signal source. The analogy of the physical conditions to the mathematical treatment is obvious.

COMPUTER SIMULATION -- The computer simulation is detailed in the following paragraphs.

Initial Conditions -- It is obvious that problem analysis becomes quite complex if all factors covering the status of the submarine, the buoys, and the aircraft are to be investigated over long periods of time. For this reason a simulation procedure for the IBM 7090 computer has been devised. Thus far, it has been applied to the contact maintenance of an on-station enemy nuclear submarine. It is assumed that the submarine is maneuvering in a non-ordered pattern, at speeds from 0 to 5 knots. This tactical situation is believed to represent a very difficult tracking assignment for an airborne system. A simple representation of the computer simulation is shown in Figure 16. Initial conditions are established by random selection of the submarine true-course, speed, and duration on a particular leg. In small time intervals, the computer updates the true submarine data and the true buoy-submarine geometry, and determines detection probabilities. Detection probability is the index of data availability to the aircraft.

Sensor Characteristics -- At this point, it is necessary to consider sensor characteristics. In Figure 17, the assumed buoy characteristics are presented. The curve at the left, lateral detection range, incorporates the assumption that at zero speed, a nuclear submarine will generate some machinery noise from pumps and generators and can be assigned a finite detection range (10 kiloyards). At a 15-knot transit speed, it is assumed that the submarine is detectable at 40 kiloyards. The detection range is assumed constant beyond 20 nautical miles because of convergence associated with the reliable acoustic path. The right-hand side of the curve is essentially the transmission-loss curve, smoothed for computation. It reflects the logarithmic variation associated with sonar devices.

Data Availability -- Returning to Figure 16, a random number system, indexed to probability, dictates when tactical data are available to the aircraft (Reference 10). Under actual tactical conditions, data would probably be available only in bits and pieces. The random system simulates the real data availability quite well. The aircraft side of the computer analyzes the data given, and decides whether maneuvering is required. It then updates the aircraft's status accordingly. Arbitrary statistical rules for aircraft maneuvering must be established as program inputs, and the aircraft can only maneuver within the constraints of the initial input parameters. While the program remains flexible and can incorporate nearly any maneuver that can be expressed mathematically, the computer will exercise that maneuver only when the criterion for the required maneuver is satisfied. A human TACCO could exercise judgment and, in some cases, would delay, abort, or completely eliminate maneuvers, a choice not available in this simulation program.

Aircraft Maneuvers -- In any tactical situation, unless the submarine is sitting, the relative position of the submarine with respect to the buoys changes constantly. The TACCO monitoring the situation should order maneuvers as the confidence level of the data presentation reaches some lower limit. Figure 18 shows a typical maneuver. It is an extension of the earlier passive localization case. The figure shows the aircraft flying from its original position 1 (at the lower left) and depositing buoy 1 (which was on board) ahead and beside the predicted track of the submarine. At this time, the deep unit of buoy 2 is commanded to rise, via the UHF command link, and the pilot flys the aircraft to the position of buoy 2 for retrieval. The sequence of events for an on-station maneuver is given in Figure 19.

The frequency of aircraft maneuvers is controlled by the necessity of continuously maintaining a satisfactory level of target localization. If some minimum level is violated, there is a high risk of losing the target. Therefore, buoys must be periodically moved to a new location that will hold the target satisfactorily. A total of 120 percent cumulative probability on three buoys was shown in Figure 15. The total of 140 percent immediately after an aircraft maneuver, as given in Figure 18, provides additional target coverage so that another buoy replacement would not be required for some time.

Probability, which is a measure of target distance corrected for signal strength due to target speed, is not the single basis for determination of buoy replacement. The intersection angle between the detecting rays from pairs of buoys must also be considered. For example, although the signal strength may be high when the distance between a buoy and the target is small, no accurate target fix can be made if the lines of signal transmission are nearly parallel. The computer simulation takes account of this quality reduction in the fix.

A technique for handling a target lost during a tracking mission has been incorporated into the simulation program. Ideally, the "go lost" route would not be implemented if the aircraft sensor system is tracking properly. However, after certain sporadic changes in target speed or course, the available data from a conventional buoy deployment pattern are unsatisfactory, and a special pattern is required. The recommended tracking procedure, then, is to hold the target as loosely as possible, minimizing the number of buoy movements required, while reestablishing the basic contact pattern. Here the seaplane accepts a slightly higher risk of being detected by deploying the buoy on board at a range of 10 kiloyards from the predicted position of the target. The probability that the seaplane will be detected in the hover mode at this range is about 10 percent. The seaplane immediately returns to the most remote buoy. A

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second alteration to standard procedure was that the remote buoy was commanded to rise immediately when the "go lost" routine was ordered.

During on-station maneuvers, the index of sea-state condition determines the take-off, drop, and landing modes of the aircraft. Where sea states are low, short take-offs and landings would be used to conserve fuel. In the digital program, the dividing line for VTOL maneuvers was between sea states 3 and 4. Fuel consumption, per manuever, is quite high in either case because of the full power required for take-off and landing; however, a nominal saving is experienced in STOL operations. It is the length of time between maneuvers, not the amount of fuel per maneuver, that makes the system competitive on the basis of pounds of fuel burned per hour. Typical transit distances involved in an on-station maneuver are 30 to 80 nautical miles. The time per maneuver is usually 20 to 35 minutes. While the aircraft is maneuvering, there may be a temporary break in the line-of-sight data link between buoy and aircraft. Should this interruption occupy a significant time interval, the buoys may require a short-term tape memory system which could be interrogated when the data link is reestablished.

COMPUTER RESULTS -- Several thousand hours of simulated tracking have been completed on the IBM 7090. Table 2 is a summary of some submarine track patterns and the fuel used by the seaplane while it was maintaining target contact. The seaplane had maneuvered essentially as shown in Figure 16 throughout the time spans considered.

Because the submarine tracks are generated from random inputs, it is difficult to assess which submarine maneuvers present the most exacting tracking problem for the seaplane sensor system. The average hourly fuel consumption of the seaplane, which depends primarily upon the number of maneuvers required, should be weighed heavily in estimating the more difficult cases.

The number of times the target is lost may also prove to be a good indication of the difficulty of maintaining continuous contact. In general, the results show that any submarine track which includes abrupt changes in signal strength (speed change) or quality of fix (bearing change) would present the more difficult tracking problems for a tactical coordinator.

A comparison of the fuel used by the seaplane, per hour of tracking, with that of contemporary airborne tracking systems shows that the seaplane represents a substantial improvement. No direct comparison is made regarding the relative merit of the seaplane versus the conventional fixed-wing aircraft in staying with a target. It may be stated, however, that tracking an on-station submarine with magnetic-anomaly detection (MAD) gear represents a considerably more difficult assignment, and in the assumed time frame may be impossible.

Looking at the amount of fuel burned per hour would indicate that the seaplane should be capable of staying on-station for extended time periods. Crew endurance rather than fuel limitation may then become the measure of mission length. A double, or nearly double, crew may be required to realize the full mission potential of the aircraft. Unfortunately, accomodation of a double crew requires further vehicle growth.

In one mission that was assumed to have a mean level of fuel consumption, 35 hours transpired from crew briefing to debriefing. The time in actual tracking operations was 21 hours, during which 14,000 pounds of fuel was burned. This schedule produces about 60 percent useful utilization of mission time; but it required coordinated refuelings with the previous and following seaplanes, and duty assignments inconsistent with the number of personnel on board.

One additional aspect of the data available to the TACCO showed that the quality of the fix varied. A part of the simulation results was a displacement and bearing error in the predicted target position. The human operator would see the geometry of target-buoy deployment, as it would be displayed on the TACCO console in the real mission. There are patterns which yield high quality fixes and those of low quality--thus, the display is a quality index. It is most significant that the positioning errors for the $\pm 3^{\circ}$ bearing accuracy, assumed for the buoy, is well within the acquisition range of present weapons when the quality of fix is high.

A simulation of the contact maintenance problem on the IBM 7090 computer is not intended to be a final statement of the case for the ASW mission. All of the inputs used in the program were based upon the best information available. However, in many cases the system characteristics had not been sufficiently defined to assign an absolute value to specific parameters.

The random number and probability technique used to generate submarine tracks and assess data availability is followed in lieu of a satisfactory definition of enemy submarine tactics and final sensor capability. If an estimate of the length of time and the accuracy with which a tracking mission could be carried out resulted, the computer simulation has then served the intended purpose of providing a set of guidelines to evaluate the concept. The final usefulness of the seaplane concept can be appreciated only by allowing the appropriate sub-system experts an opportunity to evaluate the results; and from such an evaluation, to establish practical limitations for application of the concept to specific Navy requirements.

CONTACT INVESTIGATION

The second major ASW problem compatible with the seaplane is that of contact investigation. As initially considered, this mission would be conducted in conjunction with a transport aircraft. An early disclosure of the ATSSS proposal showed a parachute deployment of the buoy from the P-3 aircraft, as shown in Figure 20. The seaplane would be the tactical vehicle, and would carry only two ATSSS buoys. The transport would be a buoy carrier and would use parachute deployment. In addition, it is considered that the transport would carry additional fuel for the seaplane. The transport requires the addition of accurate navigation equipment so that deployment can be made in a very accurate manner.

To establish the framework for this mission, a series of assumptions must be made. It is assumed that a contact is reported, perhaps visually, from an over-flight aircraft or from a small ship (or fishing boat) making a periscope sighting. It is further assumed that this fix might have a positioning error of as much as five nautical miles. The contact may be an acoustical one from a fixed passive array in which the initial positioning error may be 50 nautical miles. Since the data from the acoustical contact can be updated constantly as the airplane progresses on the outward track, the mission for the visual sighting of a 15-knot transiter and that of the acoustical contact are not markedly different. A third assumption considers that the area commander has placed a very high priority on entrapment of this target. Finally, it is assumed that this type of mission is ordinarily carried out and that there are aircraft and crews on immediate standby status.

Figure 21 represents a visual contact, which is assumed to be 600 miles from base. The lateral detection range of the active ATSS, for the geographical area considered, is assumed to be 30 kiloyards in 1,500 fathoms of water. The mission commander ascribes a speed to the contact, and this speed establishes the level of effort. In the figure it is assumed that a transit speed of 15 knots has been assigned. The seaplane and transport cruise speeds were 275 knots and 325 knots, respectively; however, both aircraft are dispatched together. Although the transport arrives in the tactical area and begins deployment of buoys on the Archimedes' spiral prior to arrival of the seaplane, the seaplane will be within monitoring distance when the first buoy data are available. The seaplane proceeds into the area and deposits two buoys (1s and 2s); then lands beside buoy 2s for monitoring purposes. A detection picket fence is essentially established with the planting of buoy 11, and the pattern can be abandoned at any time a positive identification is established by an earlier buoy. The advantage of the twelfth buoy will be shown, subsequently. If the estimate of submarine transit speed was not low and the initial contact area was not greater than the 75 square miles associated with the positioning error (five nautical miles), then entrapment is quite certain. If the submarine should continue on any heading at 15 knots or less from the time of initial contact, then detection with this system would be only a matter of time. Figure 22 is an index of the probability of detection as a function of the time after the first buoy is dropped. The specific assumption is that the submarine did transit at 15 knots, along any given heading, from the time of initial contact until the barrier was intercepted. This is a very specific case, which is only remotely realistic. Actually, the submarine would, in all probability, exercise evasive tactics. It can be assumed that the submarine would have a better acoustical range than the buoys (through the use of a conformal array or some other technique), and therefore could identify the active buoys beyond the buoy detection range. However, the entrapment fence would be closed before escape could be effected. If the submarine were to continue its evasive tactics, sanitizing the center region might be necessary. This can be done with buoys presently on hand--hence, buoy 12--but an additional fuel supply would be necessary for the seaplane. Several facets of this seaplane operation dictate that the seaplane should be capable of air-to-air refueling from a transport tanker. With this capability, the seaplane (with the buoys already deployed in the water) can sanitize the center area in 12 buoy movements, requiring approximately four hours of rather difficult work.

This mission has been considered as requiring active ATSSS (3,000-pound buoys) to prevent escape of the most quiet boats. It may be reasoned that the 15-knot transiter is sufficiently noisy to allow the use of passive mode buoys. This would have the advantage of denying deployment information to the target and establishing the entrapment fence with less expensive buoys.

Perhaps the initial assessment of target threat should include an assumption as to boat propulsion system. The quiet diesel-electric system might require the more expensive active-buoy system; but concurrently, the transit speed assessment will lower the level of effort applied. Obviously, it is difficult for the aircraft designer to more than suggest a mission capability in this case, where tactical doctrine is so questionable. The reality of this mission description is uniquely dependent upon a doctrine committing a large expenditure of personnel and equipment to an individual entrapment.

TEMPORARY BARRIER

The third ASW mission for which the seaplane is ideally suited is the temporary barrier. This role takes advantage of worldwide deployment capability of the seaplane in relatively short time. Reference 7 specifies a requirement for a 2,200-nautical-mile ferry range against a 50-knot head wind as a performance level for this deployment. The seaplane demonstrates this capability within the 115,000-pound STO allowance, giving one hour reserve at a "loiter power" setting. Block time is of the order of 10 hours for the fully operational configuration.

Specialized equipment and manpower support is a natural necessity of this mission. Providing this support would suggest the coordinated use of transport aircraft. Where deployment is enhanced by high-speed transport capability, a variety of alterations in seaplane loading exists; and no conjecture will be made as to best procedure.

Although this mission has not been detailed to any specific degree in this paper, it is not difficult to imagine that a contact investigation network--in conjunction with the transport aircraft--could establish about 375 to 400 nautical miles of barrier net in a similar time frame to that used in the contact investigation, if the transit legs were of the order of 600 miles. With these buoys deployed along a line, it would be necessary to use more than one seaplane to act as monitor. Further, if a contact maintenance mission were to develop from a contact investigation in the temporary barrier, then an additional seaplane (fitted with passive buoys) would necessarily be required. An airplane so configured could be used as the second monitoring aircraft by leaving the active barrier net and concentrating on the contact maintenance, if that should be desirable.

SPECIAL-PURPOSE VEHICLE

The Navy has a variety of other missions where a seaplane, with good seaworthiness, would be advantageous. These could be air-sea rescue, submarine resupply, command control, etc. After determining the weight of such a configured vehicle, the performance curves of Figure 9 could be applied for a capability index. An exception exists in the case of air-sea rescue where a high "dash speed" may be required for the outbound leg. At the sacrifice of propeller efficiency, a dash speed of 355 knots appears feasible. However, for a 1,000-nautical-mile mission radius, careful cruise control would be required on the return leg to complete the mission within the available fuel supply.

CONCLUSIONS AND RECOMMENDATIONS

The V/STOL seaplane with its specified systems and predicted performance would provide an ASW capability not now available. This, to some extent, is dependent upon a presumption that the degree of sensor sophistication, to achieve the desired level of performance, requires that the buoys be inexpendable and that they be recovered a very high percentage of the time.

Other recognized ASW systems appear to be much less suited to prolonged passive tracking. Only an airborne system (acoustically isolated) or complex fixed-barrier arrays can amass large stores of signature data for target classification reference. Only such a self-sustaining airborne system can remain with a target long enough to establish enemy tactical doctrine. Both signature and tactics of a target aware of being tracked may be compromised by countermeasures. Achievement of the passive detection capability described in this paper will, thus, offer an important step forward in the solution of the entire ASW problem.

To have an ASW vehicle/sensor combination like the V/STOL seaplane concept ready for operational use in the 1970's, considerable work would be required in the following areas:

1. <u>Propulsion</u>

a. Engine development emphasizing low sfc at low power (regenerative cycle) and turbine speed relaxation (double shafting).

b. Propeller development, especially weight and structure, including variable camber with supersonic tip design.

c. Propeller environmentally designed for the recirculation medium.

2. <u>Aerodynamics</u>

a. A design study to establish weight and structural limits.

b. Definition of handling qualities through the transition phase of flight.

3. <u>Sensors</u>

a. Continuing development of air transportable systems.

b. Attending to the development of a purely passive buoy.

c. Leaving open the utilization of newly developed (non-acoustic) sensor systems.

4. Avionics (Navigation, Communication and Data Processing)

a. Improvements in long and short range precision navigation.

b. Relaying of tactical data through communication channels.

c. Sophistication of data reduction, analysis, and display.

5. Seakeeping

a. Development of a retractable inflatable float system, recognizing specific stowing and structural problems.

b. Testing various configurations to establish which will give the greatest attenuation of wave motion in the open-ocean; hopefully allowing crews to operate effectively in sea state 5 or greater.

6. Naval Environment

a. Investigation of the particular handling problems involved in operating over water at a disc loading of 50 pounds per square foot (sea spray, dynamic and static stability).

b. Determine the acoustic signature generated in all modes of operation (hover, take-off, landing, sitting with only auxiliary power).

Many of the development areas enumerated are included within the continuing effort to improve existing systems, and only moderate alterations would be required to adapt these improvements to the seaplane concept. Other areas, however, present problems peculiar to this vehicle and would require considerable innovations.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D.C.
September 1965

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Table 1

Aircraft Physical Characteristics

Lifting Surfaces	
Wing	
Area in sq ft	1000
Span in ft	100.0
M.A.C. in ft	10.34
Taper ratio	0.5
Aspect ratio	10.0
Dihedral in degrees	
WS 0 to WS 195	0
WS 195 to WS 600	5.5
Airfoil section	
Root	NACA 4412
Tip	NACA 4412
Flaps (plain)	Aileron 0.20c
Canard	
Area in sq ft	250
Span in ft	50.0
M.A.C. in ft	5.17
Taper ratio	0.5
Aspect ratio	10.0
Dihedral in degrees	
WS 0 to WS 60	0
WS 60 to WS 300	5.5
Airfoil section	
Root	NACA 4415
Tip	NACA 4412
Flaps (plain)	Elevator 0.20c

[redacted]

Table 1 (Concluded)

Vertical Tail	
Area in sq ft	350
Span in ft	24.5
M.A.C. in ft	14.16
Sweep (quarter-chord) in degrees	25
Airfoil section	
Root	NACA 0012
Tip	NACA 0008
Dorsal fin area in sq ft	42.0
Rudder (plain flap): c_r/c	0.30
Hull	
Length in ft	120
Width in ft	10
Height in ft	15
Cabin volume in cu ft (approx.)	3000
Propellers (reenforced synthetic fiber)	
Diameter in ft	20.0
Disc area (total) in sq ft	1884
Solidity	0.13
Engines (regenerative turboprop type) (Allison T-78 specifications increased 22 percent)	
Power Setting in shp	
Military	4682
Normal	4122
Vertical Floats (pneumatic; internally coiled)	
Diameter in ft	
Wing-tip float	3.0
Nose float	3.0
C.G. float	7.0

[redacted]

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Table 2

Summary of Submarine Tactics and Aircraft Fuel Consumption

[0 to 5-knot submarine. Averaged over a 300-hour period]

Speed Distribution	Average Course Changes in deg	Average Course Duration in hours	Seaplane Fuel Consumption in lb/hr
Predominately high and low speeds; 12 stops taking 58.2 percent of time	73	6.0	345.7
Predominately high and low speeds; 10 stops taking 29.4 percent of time	70	4.5	475.5
Even distribution; 0-4 knots only; 19 stops taking 32.5 percent of time	70	3.1	507.0
Even distribution; 0-4 knots only; 16 stops taking 17.5 percent of time	68	3.0	604.8
Even distribution; 9 stops taking 21.8 percent of time	58	4.0	616.8
Biased slightly toward low speeds; 11 stops taking 20.5 percent of time	66	3.1	650.4
Biased slightly toward low speeds; 11 stops taking 9.3 percent of time	70	4.5	682.2
Biased slightly toward low speeds; 12 stops taking 11.3 percent of time	68	4.0	711.8
Even distribution; no stops	70	3.1	730.0
Predominately high and low speeds; 11 stops taking 12 percent of time	75	6.0	803.2
Biased slightly toward low speeds; 6 stops taking 14.9 percent of time	70	6.0	814.7
Even distribution; no stops	70	4.0	898.8

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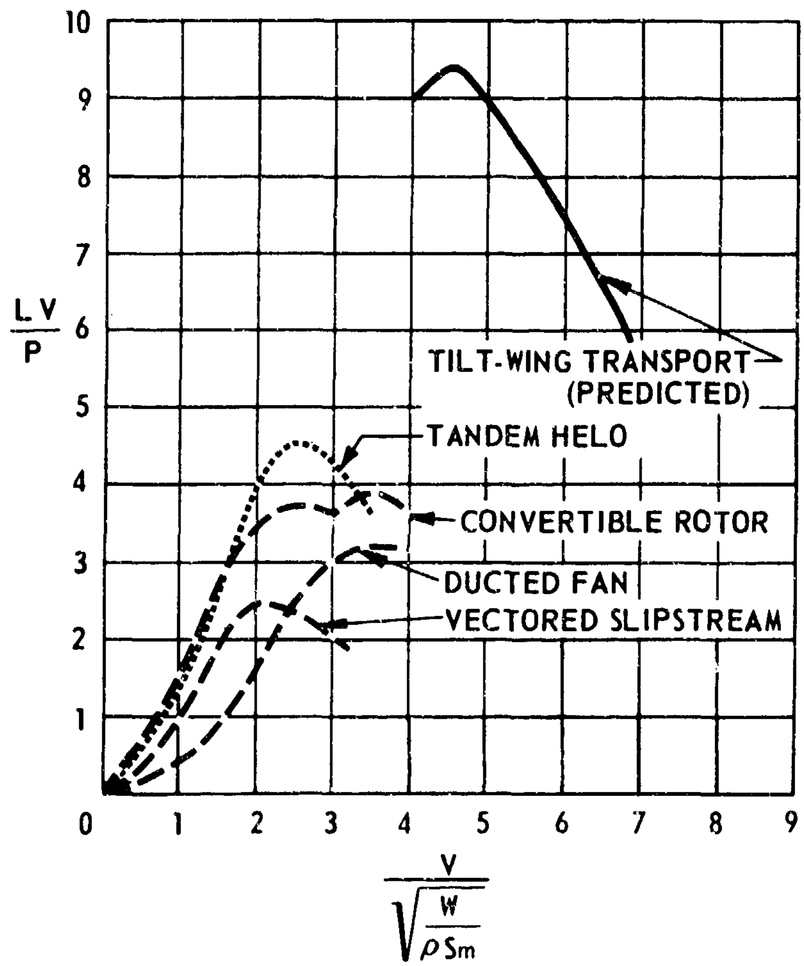

Figure 1 – Nondimensional VTOL Vehicle Comparison of Equivalent Lift-Drag Ratio versus Speed

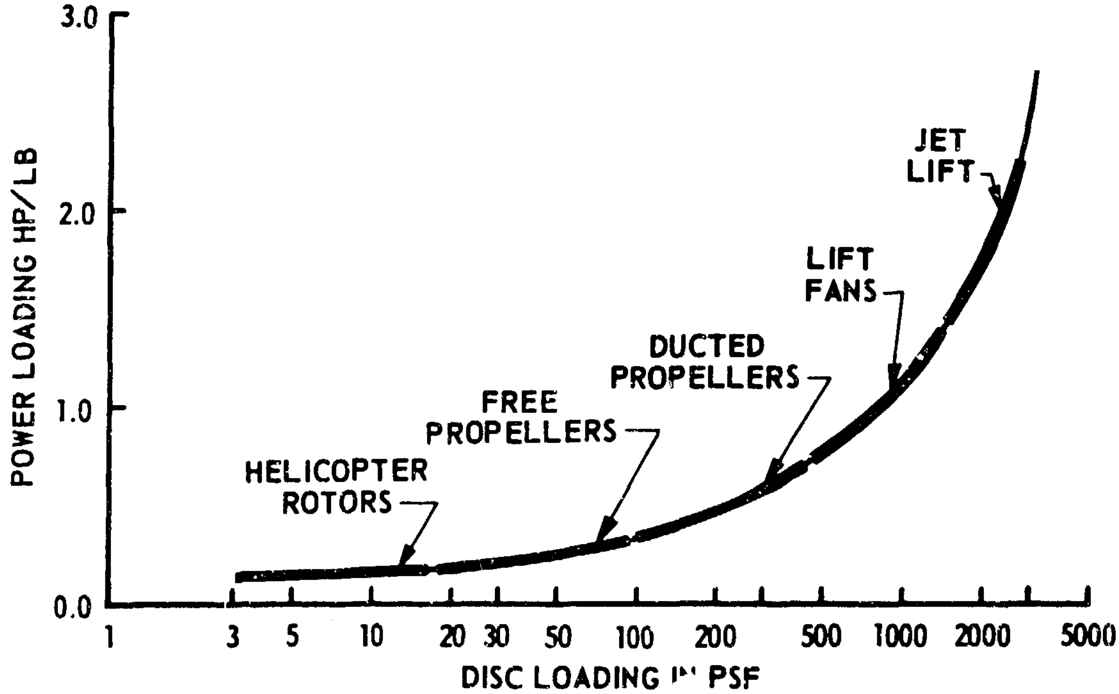

Figure 2 – Classical Propulsion System Loading for Hover Flight

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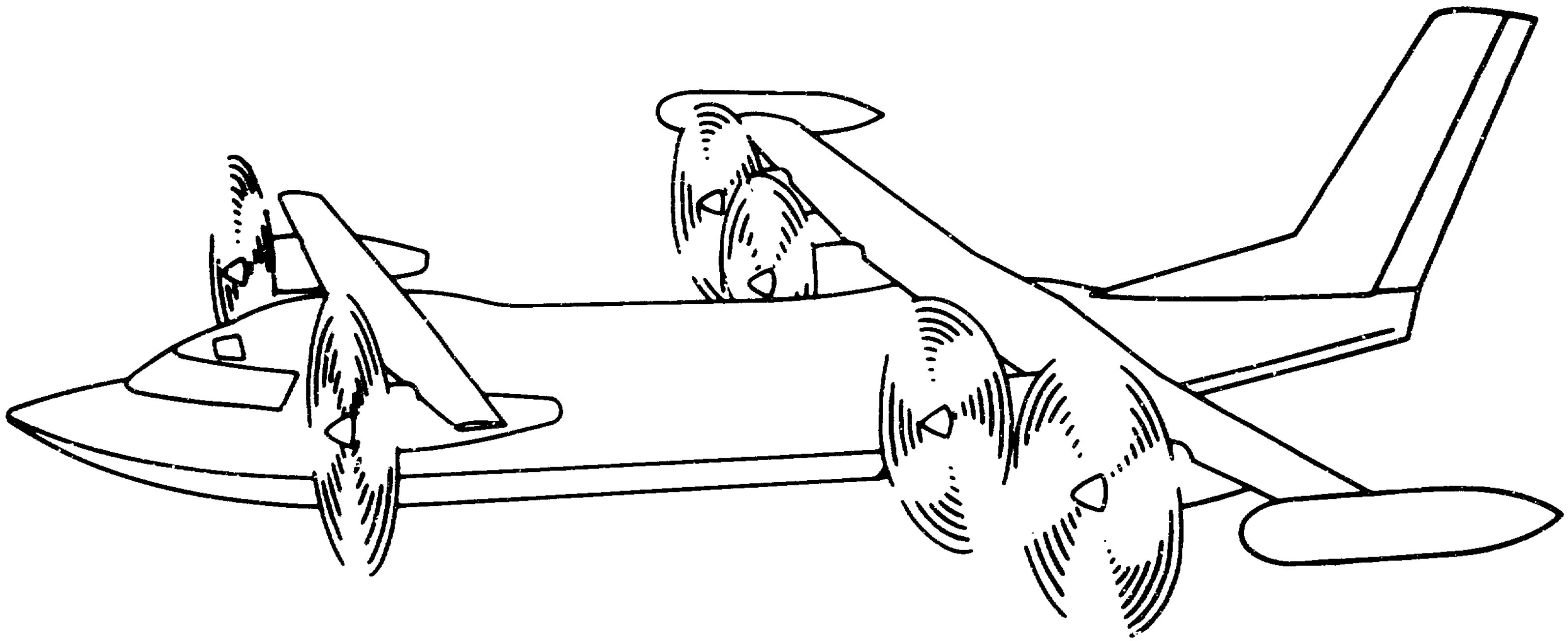

Figure 3 – V/STOL Seaplane in Cruise Configuration

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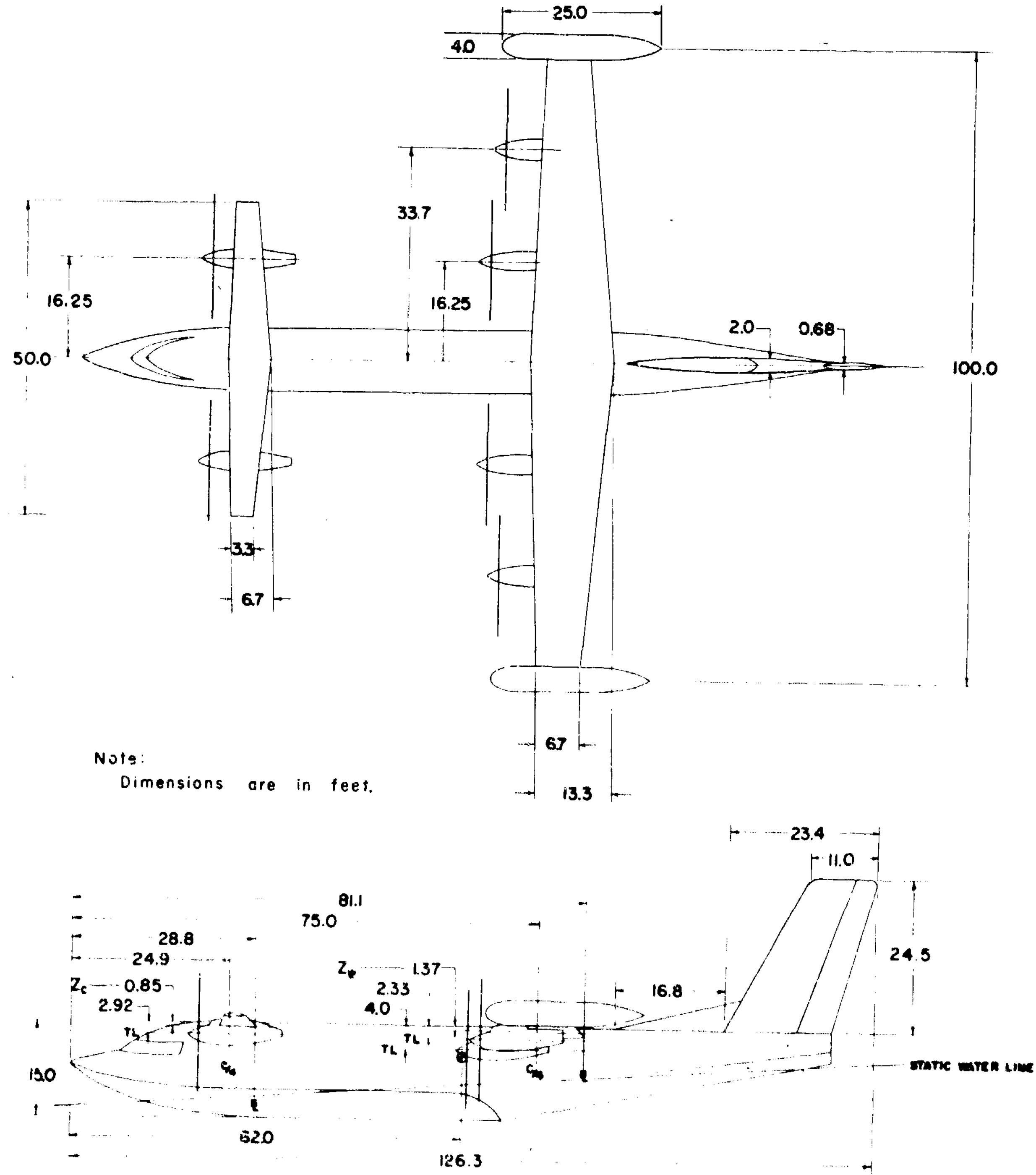

Figure 4 – Principal Dimensions of the Seaplane

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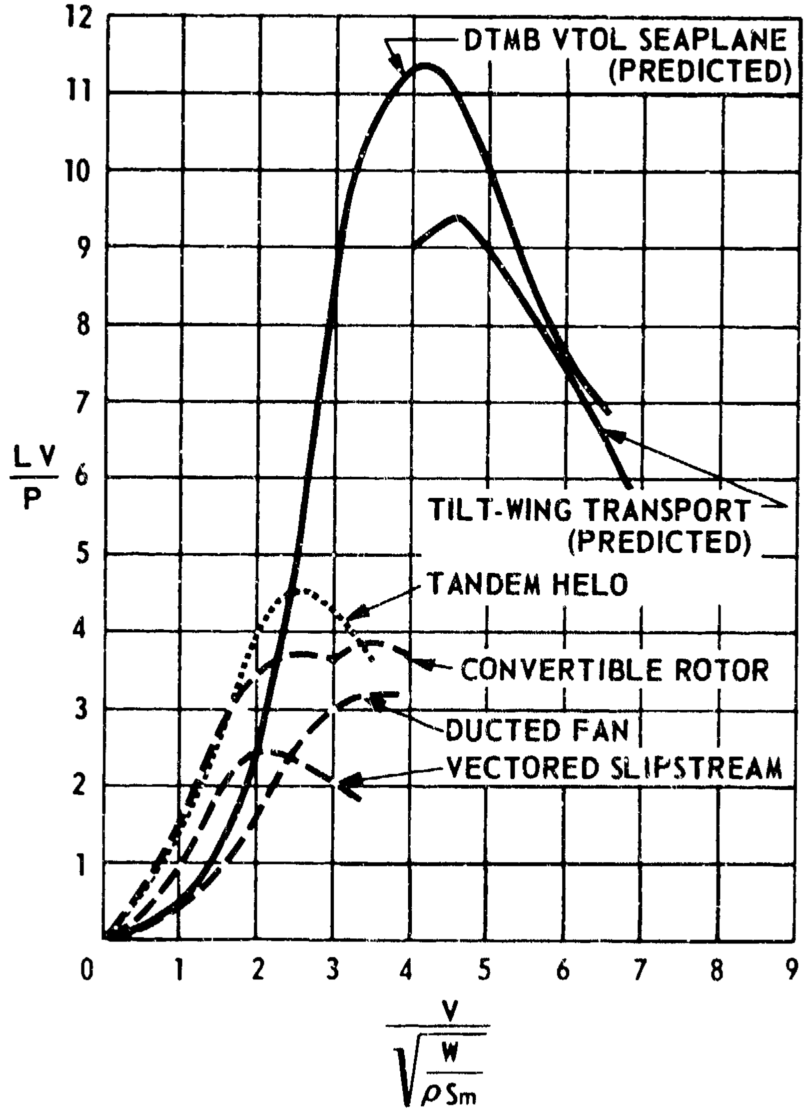

Figure 5 – Nondimensional VTOL Vehicle Comparison Including the Seaplane Design

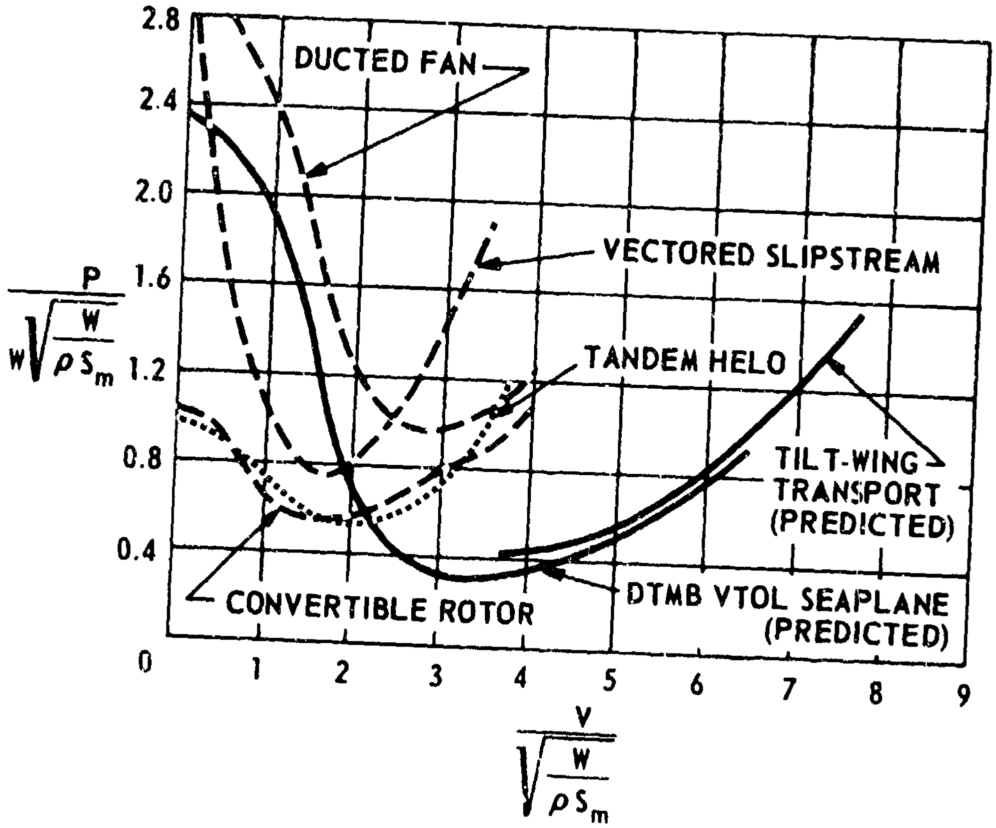

Figure 6 – Nondimensional Performance of Power versus Speed Parameters

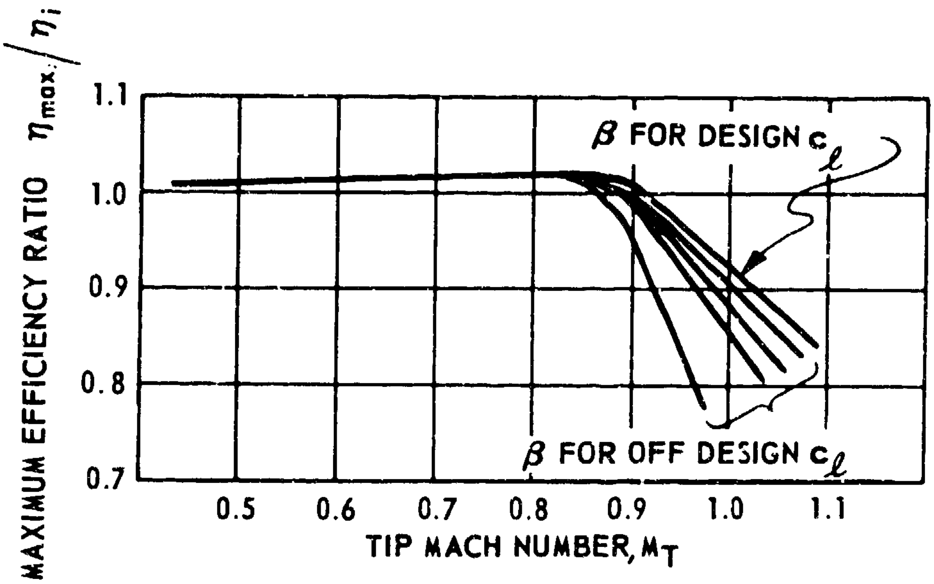

Figure 7 – Effect of Compressibility on Propeller Efficiency

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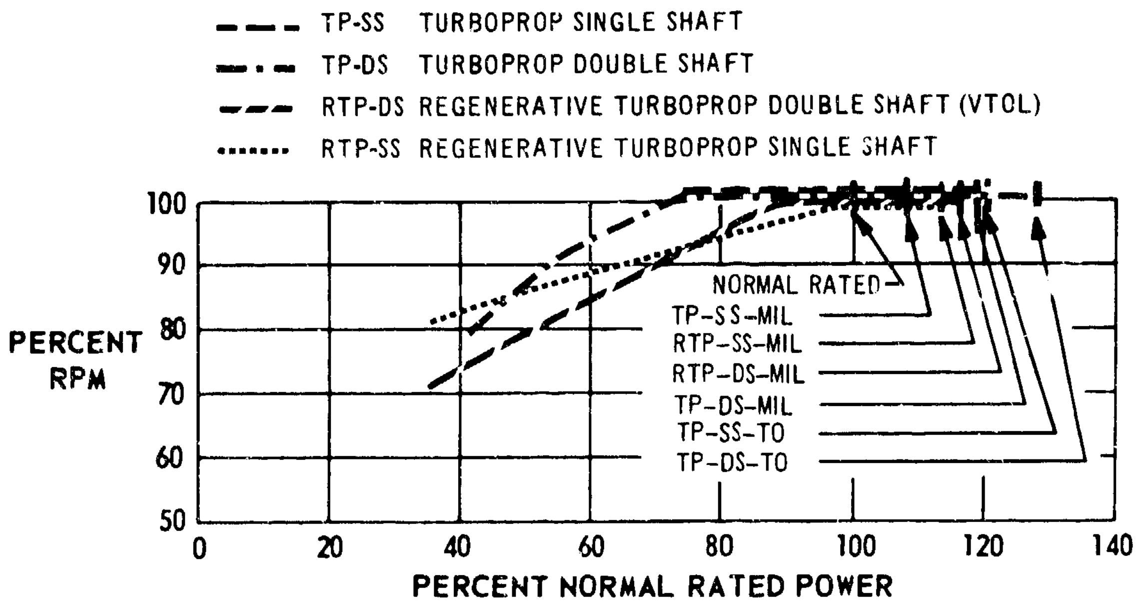

Figure 8 – Turboprop Engine Characteristics

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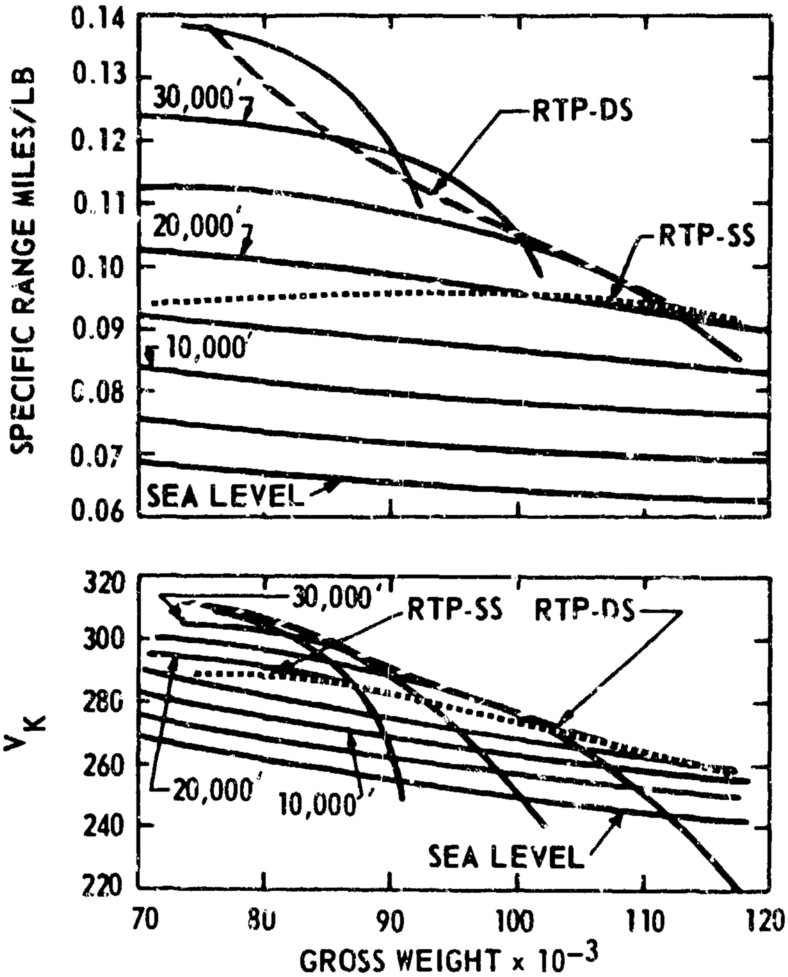

Figure 9 – Cruise Performance with Six Engines at 35-Percent Normal Rated Power
Operation was based upon $LV/P = 10.35$

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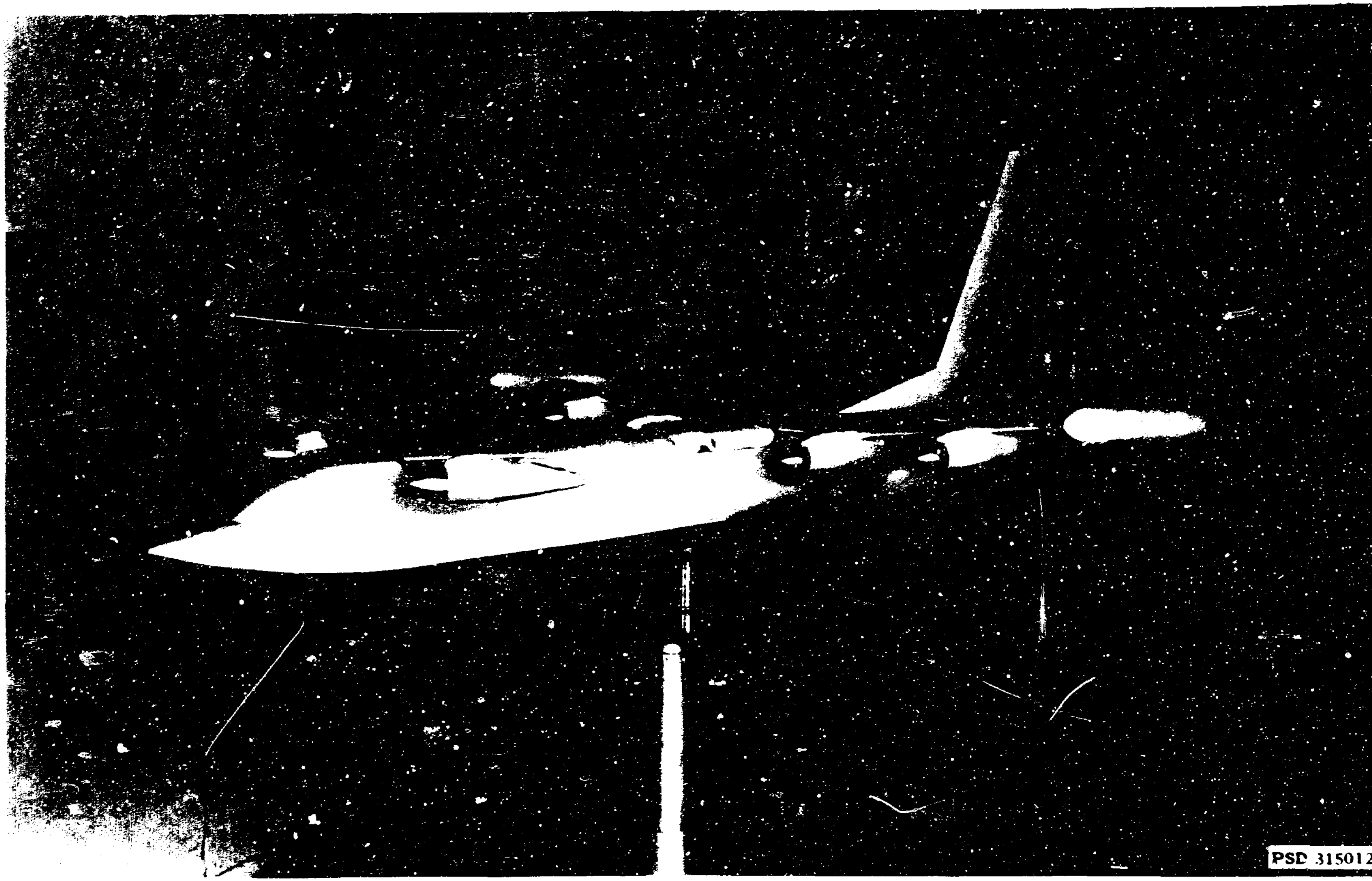

Figure 10 – The 1/20-Scale Unpowered Model in the Cruise Configuration

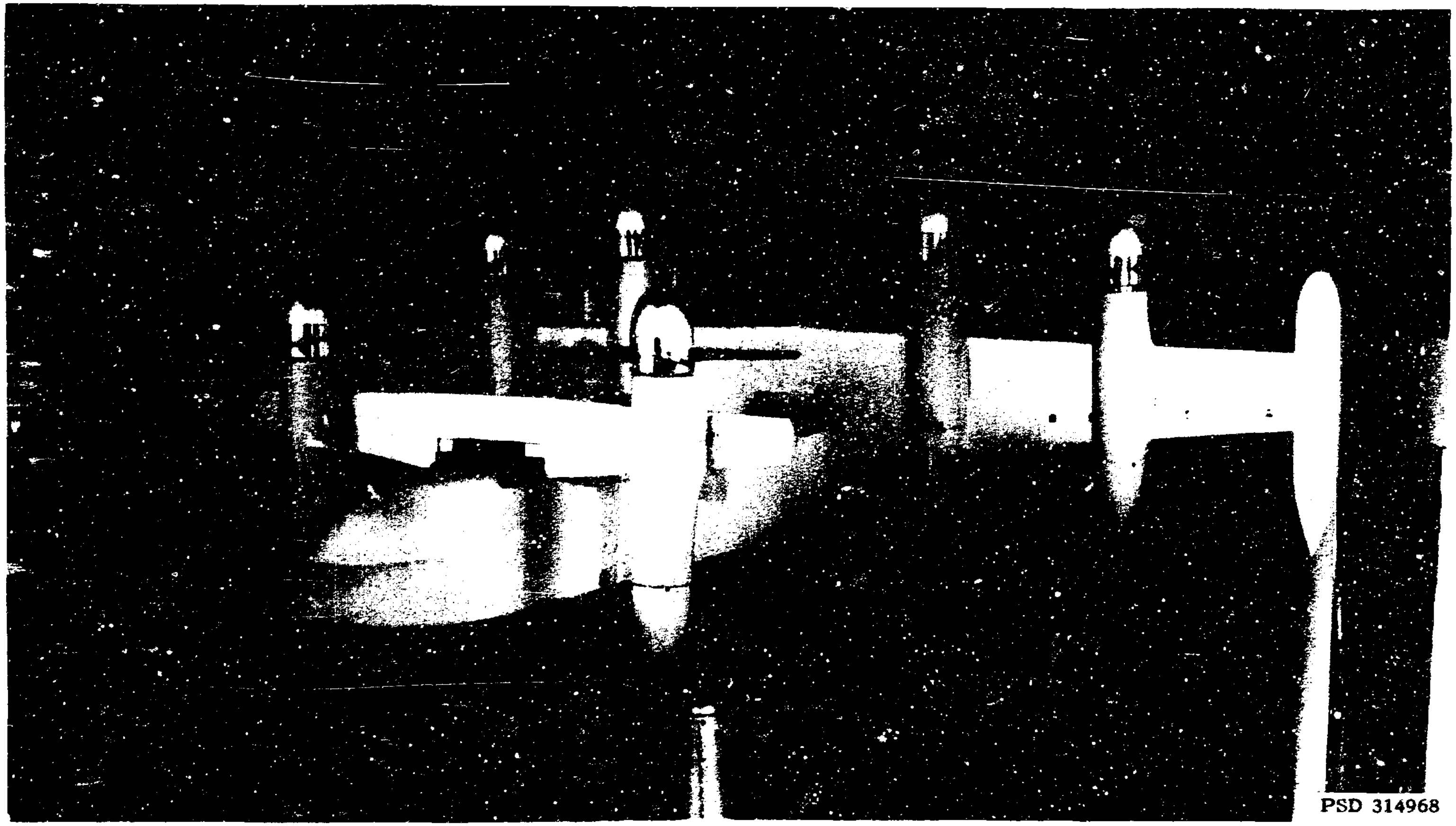

Figure 11 – The 1/20-Scale Powered Model in the Hover Configuration

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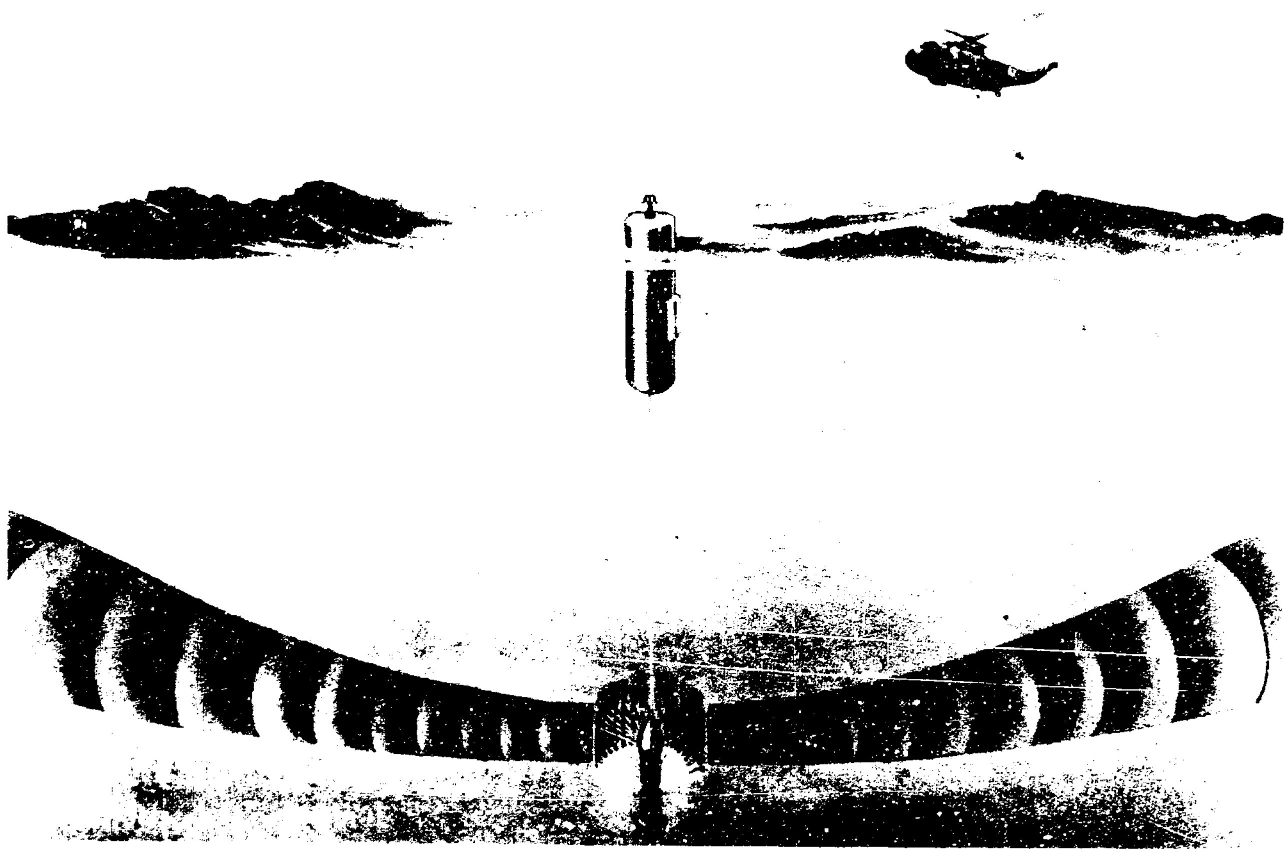

Figure 12 – Air Transportable Sonar Surveillance System (ATSSS)

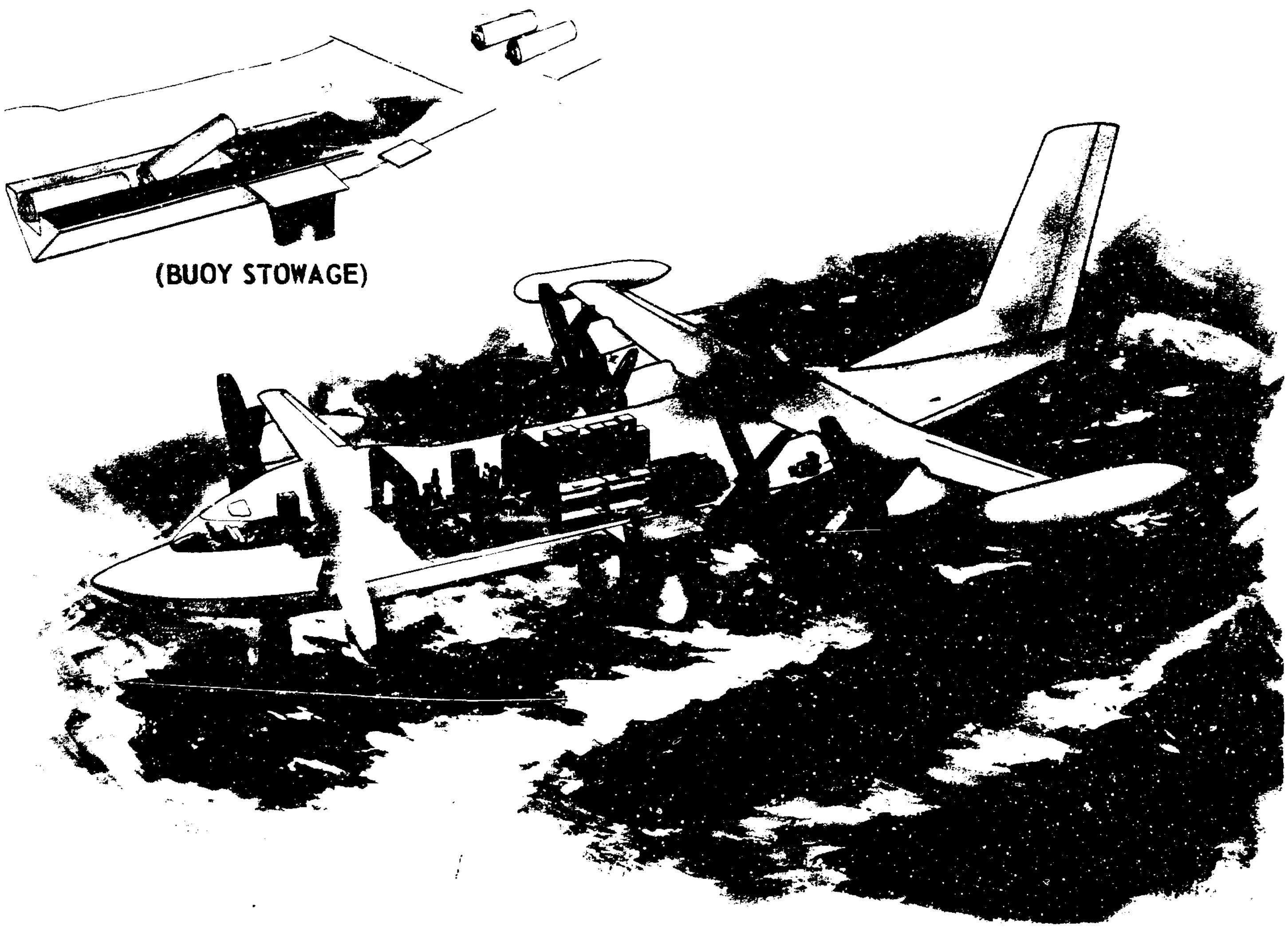

Figure 13 – Artist's Conception of V/STOL Seaplane in a Functional Layout

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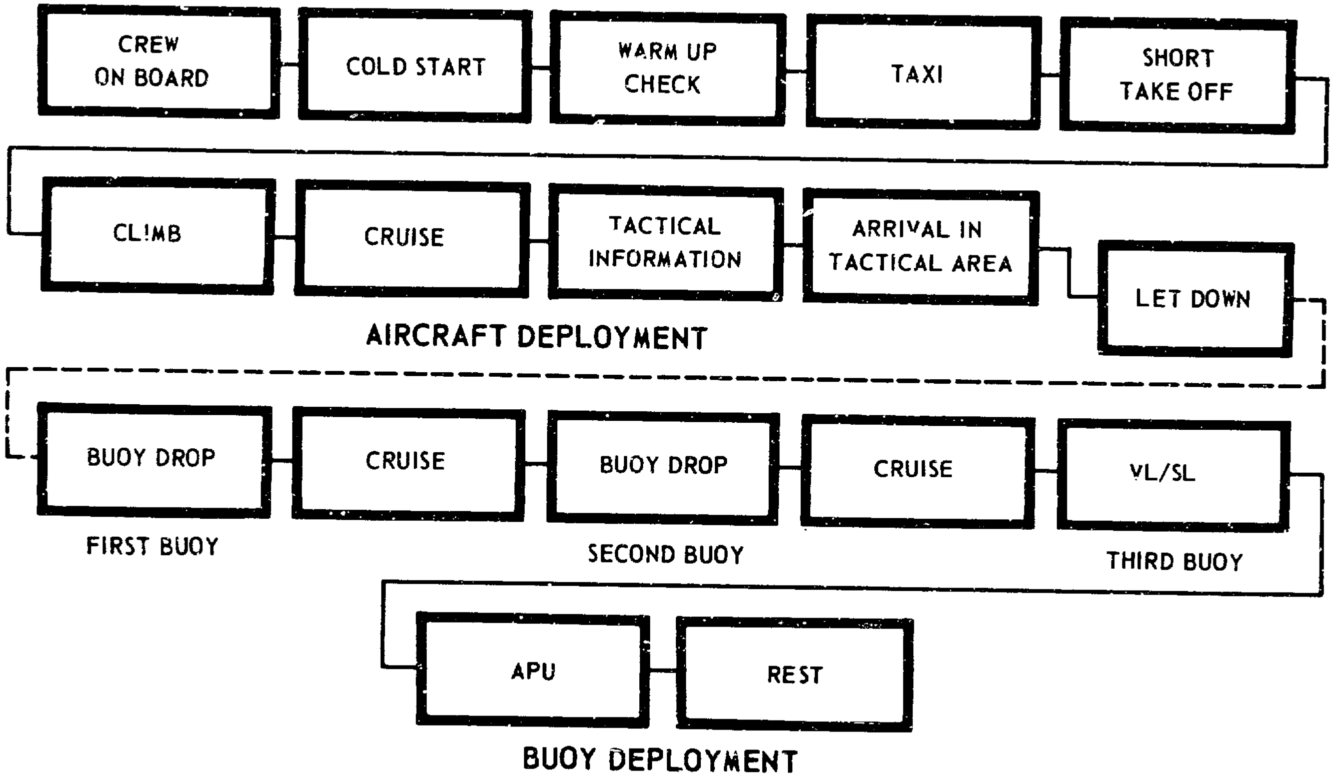

Figure 14 – Sequence for Change of Mission Command

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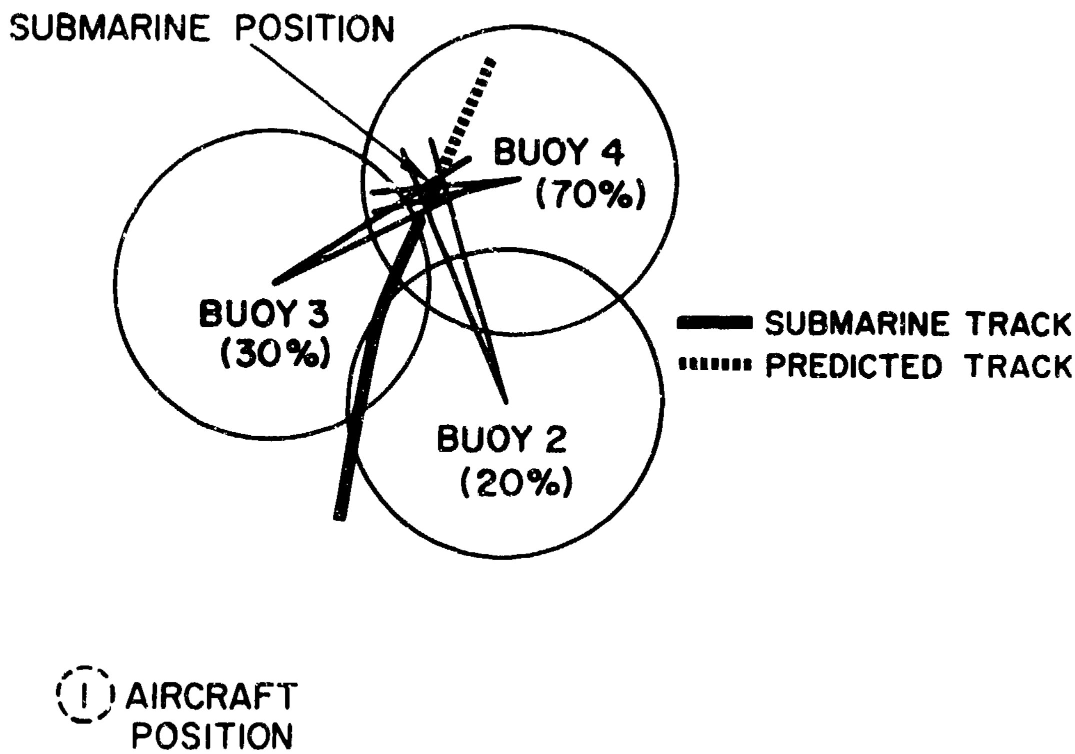

Figure 15 – Basic Tracking Mission in Contact Maintenance

Satisfactory level of passive localization, cumulative probability is 120 percent. The circles represent 40 percent detection for a 5 knot submarine.

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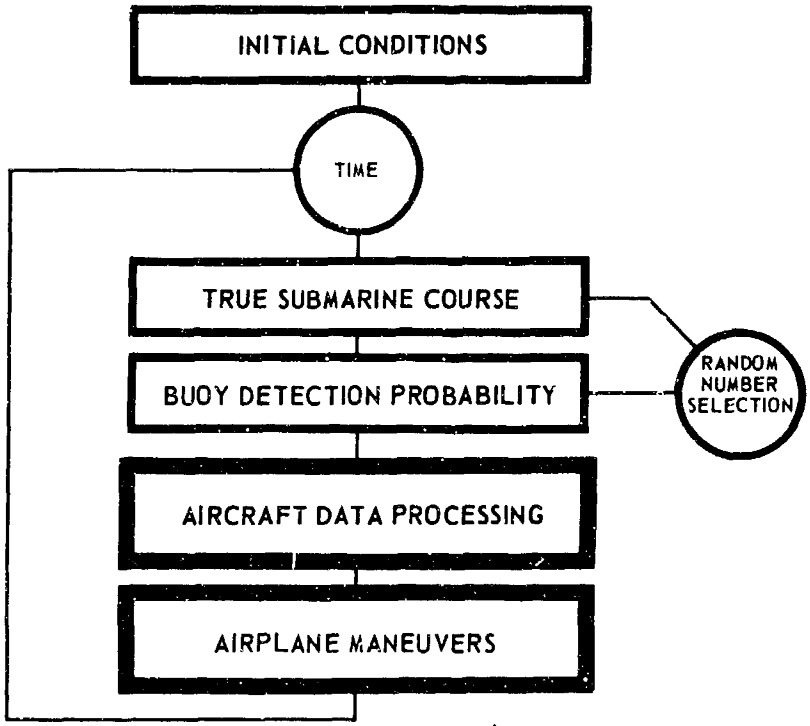

Figure 16 – Computer Simulation

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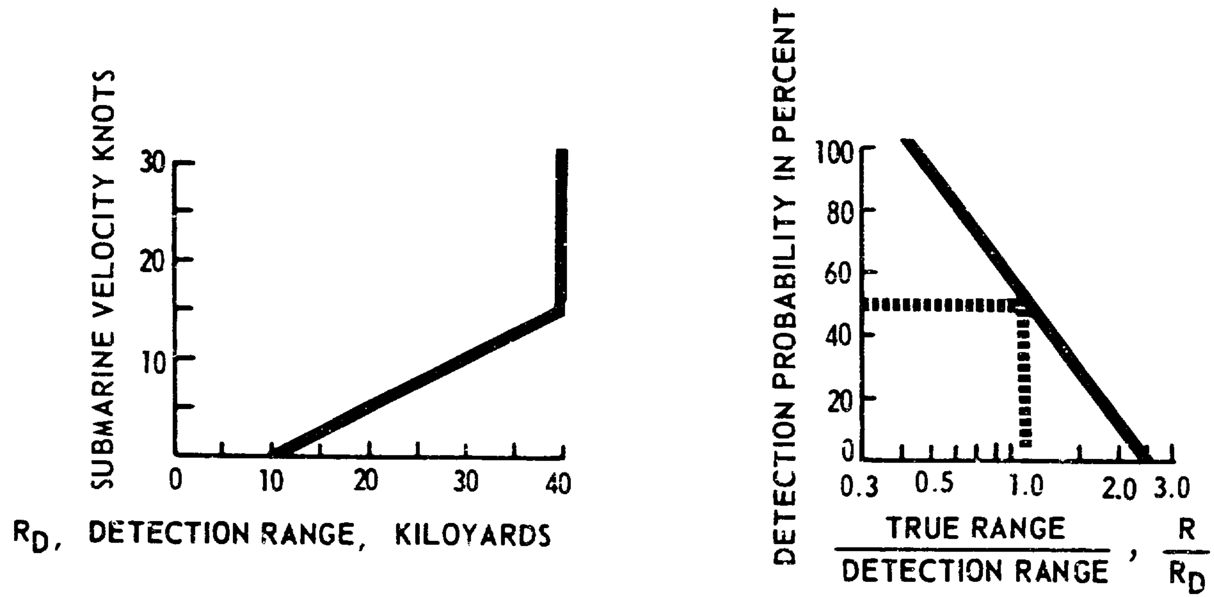

Figure 17 – Sonar Characteristics for True Range and Probability Calculations

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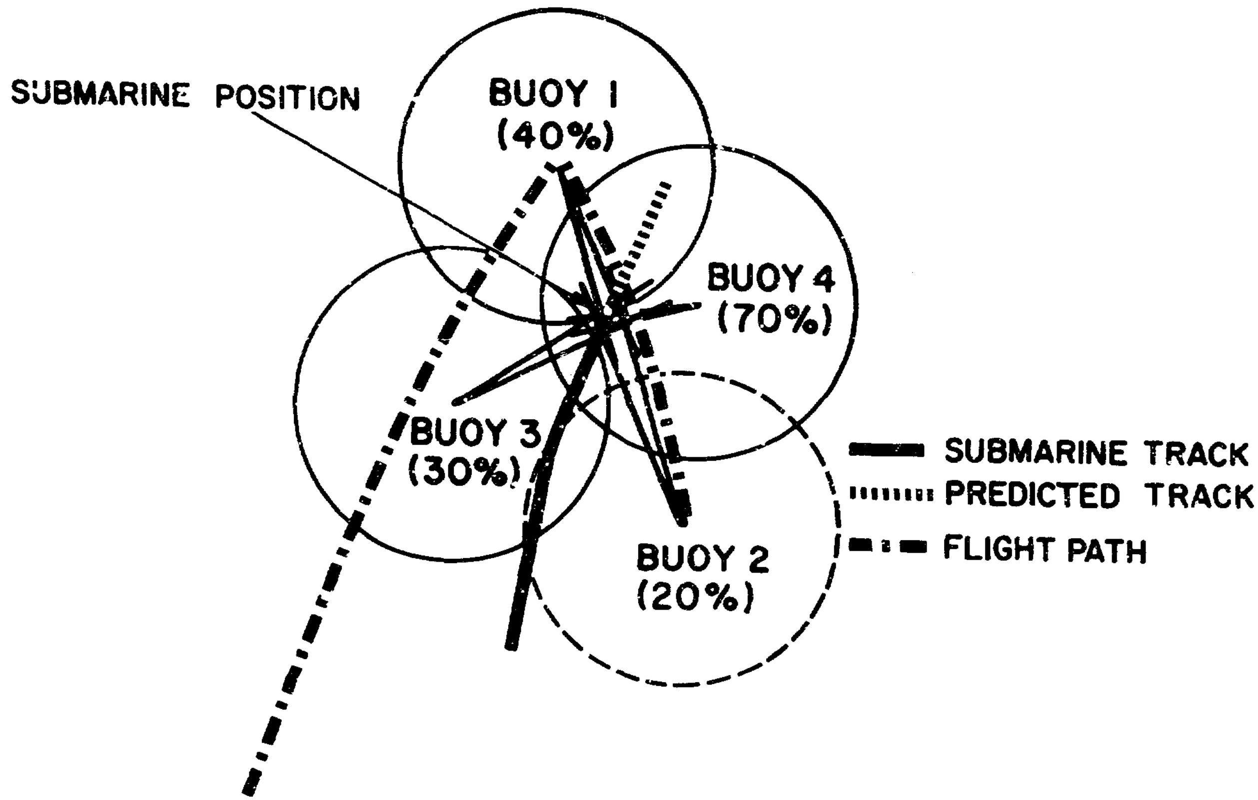

Figure 18 – Basic Tracking Mission Following a Tactical Maneuver

Post maneuver target coverage, cumulative probability is 140 percent. The circles represent 40 percent detection for a 5 knot submarine.

[redacted]

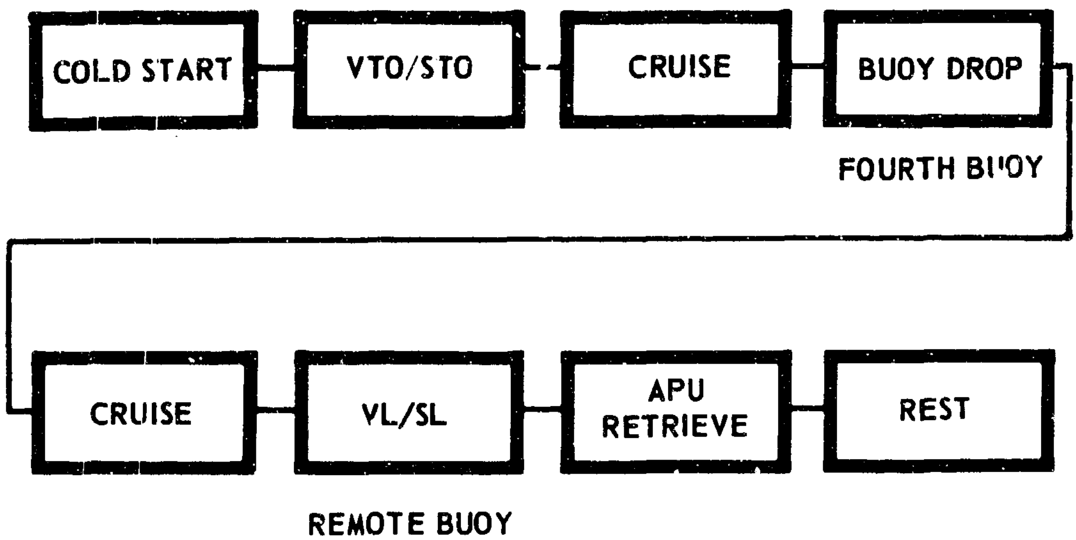

Figure 19 – On-Station Maneuver Sequence

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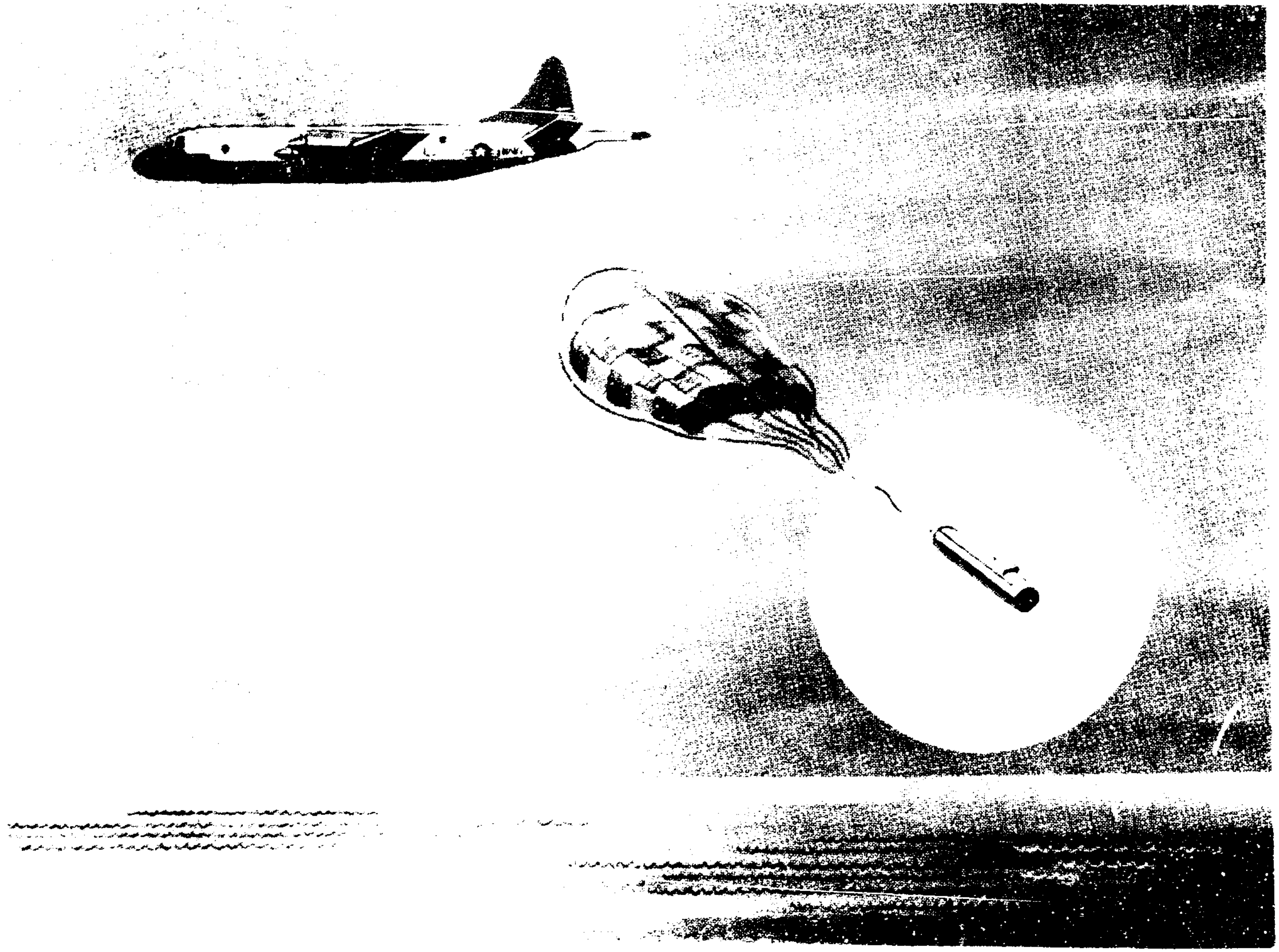

Figure 20 – Air Drop of ATSSS Buoy

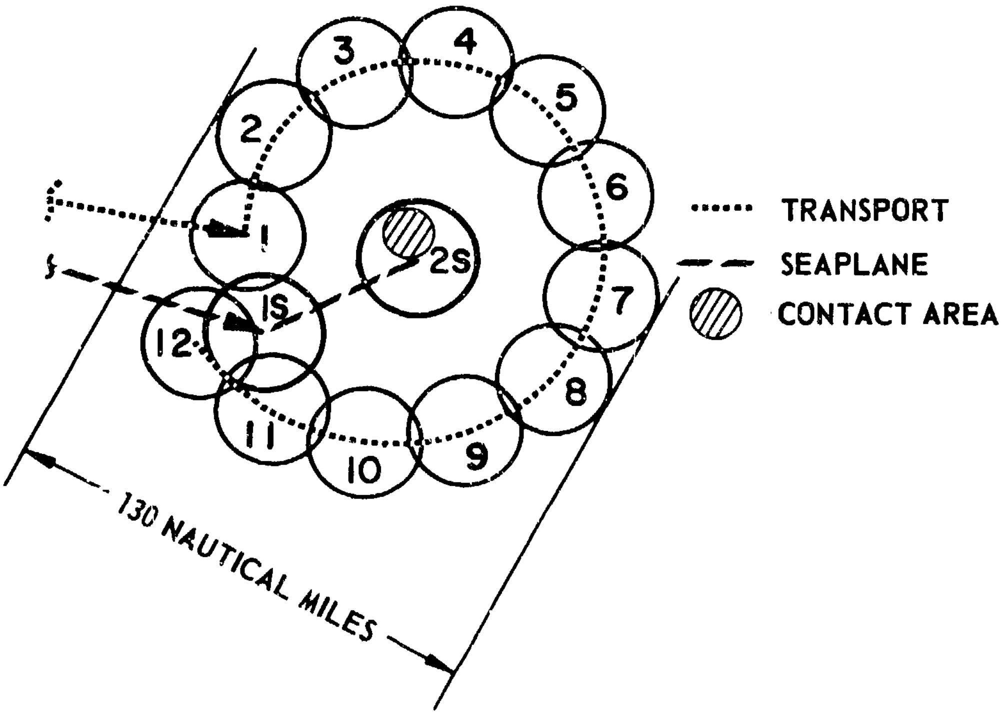

Figure 21 – Drop Pattern (Archimedes' Spiral) for Contact Investigation

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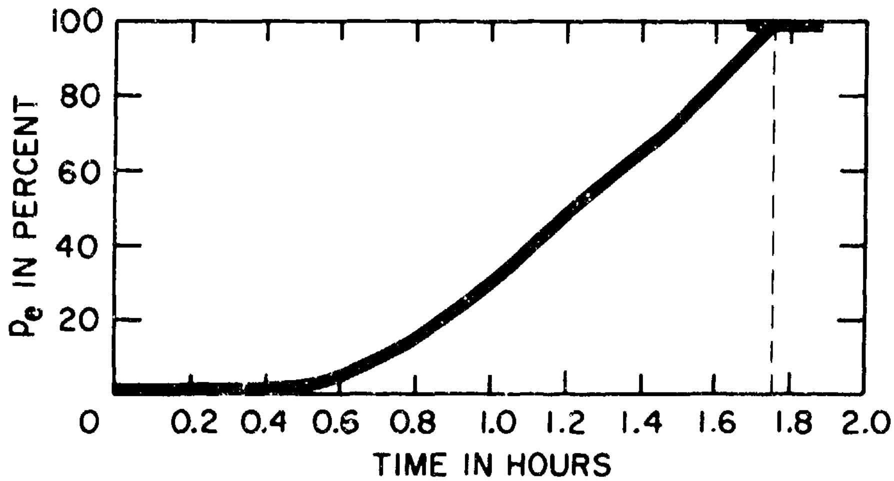

Figure 22 – Entrapment Probability p_e in Contact Investigation

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Formal Report

5. AUTHOR(S) (Last name, first name, initial)

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13. ABSTRACT

The results of preliminary vehicle design and mission-oriented operations analysis for predicted ASW systems are incorporated to form an index of tactical capability of an open-ocean seaplane. The vehicle is a canard configuration with free-propeller propulsion on tilting lifting surfaces. Regenerative cycle turbo-prop engines power six 20-foot-diameter propellers to achieve VTOL capability and efficient cruise at 275 knots for the 93,000-pound VTOL or 115,000-pound STOL aircraft. Computer simulation of mission performance covering several thousand hours indicates favorable utilization of manpower and equipment. (C)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Seaplane Design						
V/STOL						
Tilt-Wing Free-Propeller						
Canard Planform						
Vertical Floats						
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